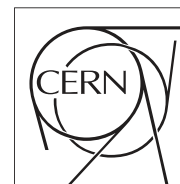


The Compact Muon Solenoid Experiment

# Conference Report

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## Observation of $W \rightarrow \tau \nu$ Production in pp Collisions at $\sqrt{s} = 7$ TeV

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### Abstract

The production of W bosons decaying into a tau lepton and a neutrino with the tau lepton decaying hadronically has been observed in LHC pp collisions at  $\sqrt{s} = 7$  TeV with the CMS detector. The selection criteria provide a statistically significant signal on the top of QCD multi-jet and electroweak backgrounds. A data-driven method for the estimation of the QCD multi-jet background has been employed.

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## 1 Introduction

Tau leptons serve as an important probe for many new physics processes at the LHC. Among others, experimental signatures that involve decays to tau leptons are crucial for searches of a light Higgs boson, Supersymmetry or extra dimensions.

Tau leptons can decay either leptonically via  $\tau \rightarrow l\nu\bar{\nu}$  ( $l=e$  or  $\mu$ , branching fraction is 36%) or into a hadronic jet and one tau-neutrino. Hadronic decay modes ( $\tau_{\text{had}}$ ) produce a highly collimated tau-jet signature, characterized by a low particle multiplicity that allows their separation from QCD-jets.

In the framework of the standard model, tau leptons are mostly produced in decays of electroweak vector bosons:  $Z \rightarrow \tau^+\tau^-$  and  $W^\pm \rightarrow \tau^\pm\nu$ . These processes have relatively large cross sections and are among the largest sources of tau leptons at LHC. The  $W \rightarrow \tau^\pm\nu$  channel benefits from a large production cross section, exceeding the production rate of  $Z \rightarrow \tau^+\tau^-$  by nearly an order of magnitude. However, the experimental signature of a single tau-jet and undetected neutrino is challenging, requiring a good understanding of the tau identification and missing transverse energy ( $E_T^{\text{miss}}$ ).

The study of  $W \rightarrow \tau\nu$  production in the  $\tau_{\text{had}}\nu$  final state is an important calibration sample for understanding tau identification and reconstruction. Also,  $W^\pm \rightarrow \tau^\pm\nu$  production has to be well understood as a test of the standard model and as a measure of important background process in several searches for new physics. In particular, it is the major background in the search for the charged Higgs boson in the  $\tau\nu$  final state.

This study of  $W \rightarrow \tau_{\text{had}}\nu$  production has been conducted using  $18.4 \pm 0.7 \text{ pb}^{-1}$  of collision data from the 2010 LHC run at  $\sqrt{s} = 7 \text{ TeV}$  recorded with the CMS detector. See Ref. [1] for a measurement of the cross section for  $Z \rightarrow \tau^+\tau^-$  production including tau-leptons reconstructed in the  $\tau_{\text{had}}$  final state.

## 2 Physics objects reconstruction

The particle flow (PF) reconstruction algorithm implemented at CMS [2] is used for identification of jets, muons, electrons, taus and  $E_T^{\text{miss}}$ . The PF technique utilizes the information from the whole event, aiming to provide a global event description at the level of individually reconstructed particles. Firstly, all tracks and energy clusters are reconstructed in each sub-detector. Next, all the candidates are associated in an optimal combination to one or more of these sub-detector signals, if they are compatible with the physics properties of each particle, and reconstructed in the event. The final set of particles (charged hadrons, neutral hadrons, photons, electrons and muons) is used to derive composite physics objects such as  $\tau_{\text{had}}$ , jets and  $E_T^{\text{miss}}$ . The PF jets are clustered using the anti- $k_T$  jet clustering algorithm [3] with distance parameter  $R = 0.5$ .

Typically,  $\tau_{\text{had}}$  is a highly-collimated jet comprising one or three charged mesons (predominantly  $\pi^\pm$ ) and possibly one or two neutral pions always decaying via  $\pi^0 \rightarrow \gamma\gamma$ . The identification of  $\tau_{\text{had}}$  from W boson decays requires a robust algorithm and an efficient set of selection criteria, as it is one of the main discriminators against large QCD jet background.

The  $\tau_{\text{had}}$  identification algorithm used here is known as the Hadrons Plus Strips Algorithm (HPS) [4]. HPS starts from a high- $p_T$  charged hadron and combines it with other nearby charged or neutral hadrons to reconstruct  $\tau$  decay modes. The identification of  $\pi^0$ s is enhanced by clustering the PF electrons and photons in "strips" along the bending plane to take into ac-

count possible broadening of calorimeter signatures because of photon conversions.

### 3 Event selection

The following list of offline selection criteria is applied for the final event selection:

- There must be at least one HPS  $\tau_{\text{had}}$  candidate with  $p_T > 30$  GeV and  $|\eta| < 2.3$ , and the leading track in the  $\tau_{\text{had}}$  candidate must have  $p_T > 15$  GeV. Three different working points (Figure 1) for the isolation has been defined [5]. The definition of the medium, which has been used in this analysis follows as: there must be no PF charged hadron or photon candidates with  $p_T > 0.8$  GeV within an isolation cone of size  $\Delta R = 0.5$ , (Those candidates which are associated to the tau decay signature are excluded.)
- Several cuts has been applied in order to rejects those electron and muons which fake taus. Furthermore we also veto the events which include good electron or muon. This cut supresses the W+Jet events where W decays either to muon or electron and jet fakes tau.
- We require  $E_T^{\text{miss}} > 35$  GeV and we consider PF jets in an event with  $p_T > 15$  GeV and  $|\eta| < 3$ , and compute the ratio,  $R_{\text{HT}}$ , of the  $p_T$  of the  $\tau_{\text{had}}$  candidate to the sum of the  $p_T$  of the PF jets. We require  $R_{\text{HT}} > 0.65$ .

Further details about event selection can be found in elsewhere [6].

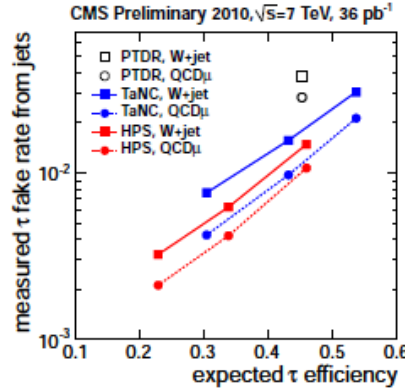


Figure 1: The measured fake rate as a function of efficiency evaluated using simulation for all working points for QCD m-enriched and W data samples. The PTDR points represent results of the fixed cone algorithm based on the PF taus

### 4 QCD Background Estimation

QCD events are the dominant background contribution to the final event sample. This background cannot be reliably estimated from simulation, so a data-driven method is used.

In the so-called “ABCD method,” four regions are designated in a phase space defined by  $E_T^{\text{miss}}$  and  $R_{\text{HT}}$ . We start with an event sample obtained with no cuts on  $E_T^{\text{miss}}$  and  $R_{\text{HT}}$ , and then divide it into four subsamples as follows

- region A where  $R_{\text{HT}} > 0.65$  and  $E_T^{\text{miss}} > 35$  GeV. This region is dominated by signal; we want to account for QCD background here.

- region B where  $R_{HT} > 0.65$  and  $E_T^{miss} < 35$  GeV
- region C where  $R_{HT} < 0.65$  and  $E_T^{miss} < 35$  GeV
- region D where  $R_{HT} < 0.65$  and  $E_T^{miss} > 35$  GeV.

In order to apply this method, we must assume that the event subsamples in regions B, C and D are dominated by QCD events, and there is a low statistical correlation between  $R_{HT}$  and  $E_T^{miss}$ . All other backgrounds have been neglected and no corrections have been applied due to the signal contribution in the B, C and D regions.

Figure 2 illustrates the transverse mass distributions of  $\tau_{had}$  candidates and  $E_T^{miss}$  in regions B, C and D. One sees that indeed these regions are dominated by QCD background. The signal contribution is less than 1% in region C, and less than 5% and 10% in regions B and D, respectively. It has been shown [6] that the level of correlation between  $R_{HT}$  and  $E_T^{miss}$  is sufficiently low to yield accurate background estimation using the ABCD method

We estimate the yield of QCD background events in the signal region A from the numbers of events observed in the other regions. Specifically, we assume  $N_A = (N_D \times N_B) / N_C$ , and obtain  $N_A = 109 \pm 6$  events, where the uncertainty is statistical only.

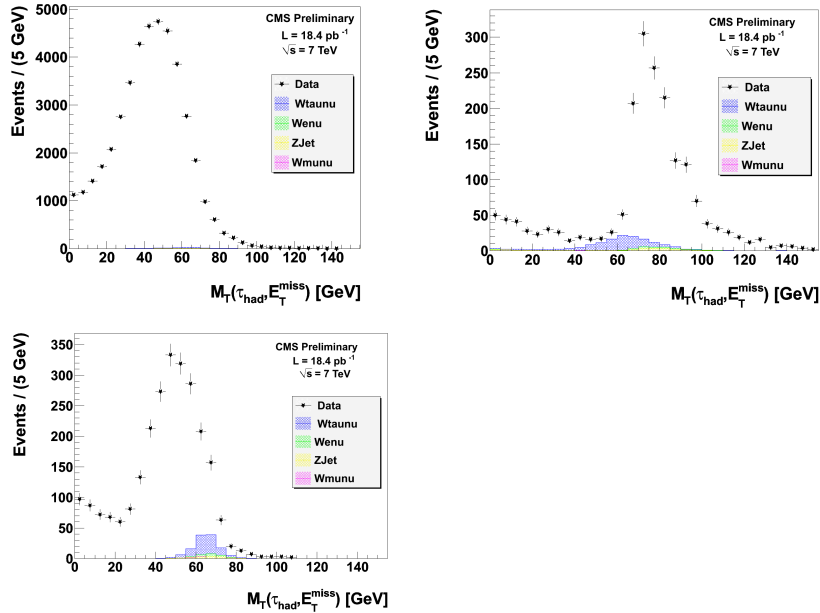


Figure 2: Transverse mass distributions of the  $\tau_{had}$  candidate and  $E_T^{miss}$  for the four designated regions in phase space: Region B (bottom left) where  $R_{HT} > 0.65$  and  $E_T^{miss} < 35$  GeV, Region C (upper left) where  $R_{HT} < 0.65$  and  $E_T^{miss} < 35$  GeV, and Region D (upper right) where  $R_{HT} < 0.65$  and  $E_T^{miss} > 35$  GeV. The points represent the data. Simulated signal and electroweak backgrounds are represented by the filled histograms.

## 5 Results

After all selections, the expected yield of  $W \rightarrow \tau\nu$  events as well as electroweak background contributions are estimated using simulation while the QCD multi-jet background is estimated from the ABCD method described above. With the selections used in this analysis, number of signal event is estimated to be  $174 \pm 3$  (stat), the number of electroweak backgrounds (domi-

nated by  $W \rightarrow e\nu$ ) is estimated as  $46 \pm 2$  (stat) and the QCD multijet contribution is  $109 \pm 6$  (stat). The number of events observed in data is 372.

It should be mentioned that we have not yet assessed systematic uncertainties on the background predictions or on the signal efficiency.

The shape of the transverse mass distribution for QCD multi-jet events is estimated using a data-driven method. The strategy is to relax some cuts to move into a region where QCD is dominant, and normalize this shape to the number of QCD events estimated with the ABCD method. Figure 3 shows that when changing the isolation criterion or the  $R_{HT}$  cut (from 0.1 to 0.5), the QCD shape does not change drastically. We decided to use a working point where the contribution of electroweak processes and signal events under the mass peak is reduced to 15%, loosening the cut on  $R_{HT}$  from 0.65 to 0.3 and using a looser isolation requirement.

Figure 4 shows the transverse mass distribution for the final event sample, with the data-driven estimate of the QCD contamination.

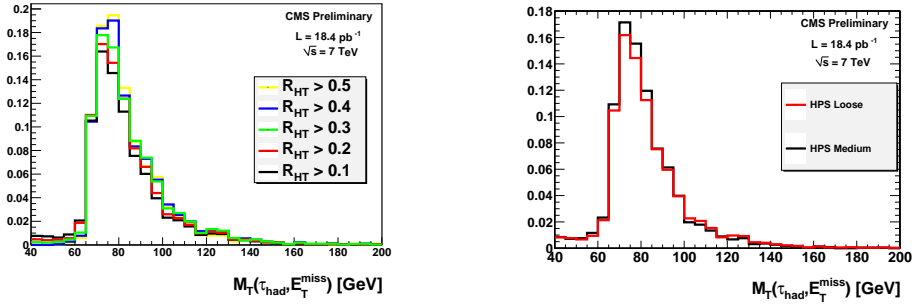


Figure 3: Effect of changing the  $R_{HT}$  and isolation criteria on the shape of Transverse Mass of  $\tau_{had}$  and  $E_T^{miss}$ .

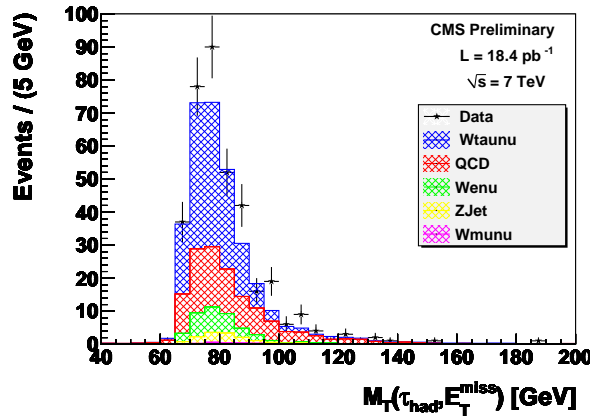


Figure 4: Transverse Mass of  $\tau_{had}$  and  $E_T^{miss}$  after all cuts

## 6 Summary

We have statistically significant signal for  $W \rightarrow \tau_{had}\nu_\tau$  with the  $\tau$ -lepton reconstructed in its hadronic decay modes, using  $18.4 \pm 0.7 \text{ pb}^{-1}$  of data collected by the CMS Collaboration.

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